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Original communication

Age estimation by measuring open apices of lower erupted teeth in 12–16 years olds by radiographic evaluation

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ABSTRACT

The purpose of this study was to estimate chronological age from panoramic radiographs by measuring open apices of seven right or left mandibular teeth in children of South Indian origin. A total of 101 male and female patients aged between 12 and 16 years were selected. The panoramic radiographs of the patient were indirectly digitised. The variables $N0$, $x3$, $x4$, $x5$, $x6$, $x7$ and s were measured using a computer-aided drafting program. Statistical analysis was performed to derive a regression equation for estimation of age. Two variables $x3$ and $x7$ contributed significantly to the fit, yielding the following linear regression formula: Age = 16.025−9.445 ($x7$) + 1.620 ($x3$). Statistical analysis indicated that the regression equation explained 97.5% of total variance (R^2 = 0.975). The median of the residuals was −0.0348 years with an interquartile range (IQR) of 0.2520 years. The derived regression equations from these variables can serve as an invaluable tool in estimating the age of children between 12 and 16 years of South Indian origin.

1. Introduction

Forensic odontology is a vital and integral part of forensic science that is most widely used for identification of the living and deceased persons.[1]

In recent years estimation of age of living persons plays a pivotal role in establishing the identity of the person. Age estimation is imperative in both forensic and clinical work. For forensic purposes, the problem of age estimation concerns how close the actual age is to the minimum age for criminal responsibility in various countries. From a legal perspective, age estimates are carried out to determine whether a suspect without valid identification documents has reached the age of criminal responsibility and whether general criminal law in force for adults is applicable in the particular case. In many countries, the age thresholds of relevance to criminal prosecution lie between 14 and 18 years.[2]

In India the issues of concern are high rate of child marriages, large numbers of child labourers and children trafficked for commercial and sexual exploitation. Most children are forced into these activities and the age estimation in such individuals is therefore crucial.[3] Age estimation also plays an important role in paediatric endocrinology, archaeology and clinical dentistry in orthodontics diagnosis and treatment planning and in developmental disorders.[4]

During the growth of a person, the application of skeletal, odontological, anthropological and psychological methods allows an approximate assessment of age.[5] Among the methods most frequently used for skeletal maturity are those concerning the left hand-wrist area (e.g., Tanner–Whitehouse[6] and FELS[7] methods), which can produce estimates up to the age of 16 years, at which time wrist maturation is completed in 90% of subjects. However, these skeletal methods present some drawbacks in view of the important variability of bone maturation, which is influenced by environmental factors and higher radiation dose. An alternative approach based on dental development is suitable for age determination in children because the calcification rate is controlled more by genes than by environmental factors, and therefore yields lower variability.[8–10] In 2001 and recently in 2008, the Study Group on Forensic Age Diagnostics stressed the study of the dental and skeletal areas as fundamental for age estimation.[11]

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Teeth are most frequently analysed for age estimation. The high number of teeth and the continuous modification of both crown and root in children mean that several methods of age estimation can be applied.[12] In 1973, Demirjian et al.[13] studied one method of age estimation based on dental maturation of third molars on children of French–Canadian origin. Their data were later compared with other sample groups from several nationalities. Most of the results revealed the fact that the standards of dental maturation described by Demirjian et al. are not always suitable for other countries.[14,15] Although these studies validated the method, they also highlighted the need to apply a particular regression model to each country.[12]

In 2006, Cameriere et al.[5] presented a method for assessing chronological age in children based on the relationship between age and measurement of open apices in teeth, which gave reliable estimates of the ages of 455 Italian Caucasian children. The present study was undertaken to assess the chronological age in children aged between 12 and 16 years based on the relationship between age and measurement of open apices of teeth on panoramic radiographs. The purpose of the present research is to derive a specific formula for Indian children based on Cameriere's method.

2. Materials and methods

A total number of 101 patients, 52 males and 49 females, aged between 12 and 16 years (Table 1) were selected from the Dental Outpatient Department of Oral Medicine and Radiology, M. S. Ramaiah Dental College and Hospital, Bangalore. Approval from the ethical committee of the institution was obtained regarding the study. Informed consent was taken from all the parents of the patients explaining the aim and methodology of the study. The patients were subjected to panoramic radiographs as a part of routine diagnostic procedure for their orthodontic treatment between 2008 and 2010.

Individuals with the following conditions were included in the present study. All teeth on the right/left lower jaw should be present, appropriate for the age group of 12–16 years, and either the right or the left lower side of the jaw was considered for study. Individuals should be of ethnic origin from South India (history confirmed up to two generations). Individuals with the following conditions were excluded from the present study: Third molars, radiographs that were unclear showing any pathology on the concerned side of the lower jaw, ex-developmental abnormalities, grossly decayed teeth, tooth fractures, cysts or tumours and patients with previous history of orthodontic treatment.

The radiographs were then digitised using a flatbed scanner (EPSON Perfection V 700 PHOTO), and the images were recorded on computer files.

Table 1
Distribution of study samples by age groups and gender.

Age	Gender		Total
	Male	Female	
12	16	12	28
	57.1%	42.9%	100.0%
13	12	12	24
	50.0%	50.0%	100.0%
14	12	7	19
	63.2%	36.8%	100.0%
15	10	12	22
	45.5%	54.5%	100.0%
16	2	6	8
	25.0%	75.0%	100.0%
Total	52	49	101
	51.5%	48.5%	100.0%

For each individual, the following parameters were considered. The chronologic age of an individual was calculated by subtracting the birth date from the date on which the radiographs were exposed for that particular individual after converting both to a decimal age by the method of Eveleth and Tanner.[16] Decimal age was taken for simplicity of statistical calculation and age was estimated on a yearly basis, for example, 12 years 9 months as 12.75 years and was considered in the 12 years' age group.

The images were processed using a computer-aided drafting program, Adobe Photoshop 7. With the help of Adobe Photoshop 7 the following parameters were calculated with the measure tool. The measure tool is present on the drop down column on the left hand side of the Adobe Photoshop. It was used to measure the length of the tooth and the distance between the open apices. The number of right or left permanent mandibular teeth with root development complete, apical ends of the roots completely closed, was calculated and denoted as ($N0$). In teeth with incomplete root development, and therefore with open apices, the distance between the inner sides of the open apex was measured. For teeth with one root, the distance between the inner sides of the open apex was measured and denoted as Ai, where $i = 1, 2, 3, 4, 5$ (1, central incisor; 2, lateral incisor; 3, canine; 4, first premolar; 5, second premolar) (Fig. 1). For teeth with two roots, the sum of the distances between the inner sides of the two open apices is calculated and denoted as Ai where, $i = 6, 7$ (6, first molar; 7, second molar) (Fig. 1).

Due to the possible differences in magnification and angulations among X-rays, measurements (Ai) were normalised by dividing (Ai) by tooth length. Tooth length is measured from the point of highest cusp to the root apex and is denoted as (Li) (Fig. 1).

Dental maturity was evaluated using the normalised measurements of the seven right or left mandibular teeth ($xi = Ai/Li, I = 1,\ldots, 7$). Therefore, the sum of the normalised open apices is, $S = (x1 + x2 + x3 + x4 + x5 + x6 + x7)$.

Fig. 1. An example of tooth measurement. Ai, $i = 1,\ldots, 5$ (teeth with one root), is the distance between the inner sides of the open apex; Ai, $i = 6, 7$ (teeth with two roots), is the sum of the distances between the inner sides of the two open apices; and Li, $i = 1,\ldots, 7$, is the length of the seven teeth.

Measurements were carried out by two different observers. Assessment of intraobserver and interobserver reproducibility was checked on a random sample of 40 panoramic radiographs after an interval of 2 weeks. All the morphological variables, $x3$, $x4$, $x5$, $x6$, $x7$, S, $N0$ and subjects' gender, were entered in an EXCEL file for use as predictive variables for age estimation in the subsequent statistical analysis. Chronological age, calculated by subtracting date of birth from the date of radiograph, was also recorded in the EXCEL file.

3. Statistical analysis

For each individual, all the morphological variables, xi, $I = 1,\ldots, 7$, s, $N0$ and gender, were entered in an EXCEL file to be used as predictive variables for age estimation in subsequent statistical analysis. Chronological age, calculated by subtracting the date of the radiograph from the date of birth, was also recorded.

The interobserver reliability of the sum of normalised open apices (s) was studied by means of the concordance correlation coefficient, and κ statistics were used to measure the intraobserver reliability of the number of the seven right permanent mandibular teeth with root development complete ($N0$).

Furthermore, correlation coefficients were evaluated between age and predictive variables. To obtain an estimate of age as a function of the morphological variables and subjects' gender, a multiple linear regression model was developed with first order interactions by selecting those variables that contributed significantly to age estimations using the stepwise selection method. Statistical analysis was performed with Statistical Package for Social Sciences (SPSS) version 17.5% statistical program. The significance threshold was set at 5%.

4. Results

There were no statistically significant interobserver and intraobserver differences between the paired sets of measurements carried out on the re-examined panoramic radiographs. Pearson's correlation coefficients between age and morphological variables showed that all of them were significantly correlated with age.

When all the variables were entered in the EXCEL file for statistical analysis, it was found that of the variables $x3$, $x4$, $x5$, $x6$, $x7$, S, $N0$, and gender, the variables $x3$ and $x7$ were statistically noteworthy and contributed significantly to the fit (Table 2). These two variables were used to derive the linear regression formula:

$$\text{Age} = 16.025 - 9.445(x7) + 1.650(x3). \tag{1}$$

The derived variables ($x3$ and $x7$), calculated from the panoramic radiographs of different children, were applied on the regression equation and the adjusted age/predicted age was calculated. When the adjusted age was compared to the chronological age it was found that the regression equation with selected variables explained 97.5% of total variance ($R^2 = 0.975$). The standard error of estimate is 0.20751 (Table 3). The median of the residuals, that is the adjusted age minus the predicted age, is 0.0348 years. The median of the residuals (=observed age minus predicted age), was −0.0348 years with interquartile range (IQR) = 0.2520 years (Table 4).

The graph (Fig. 2) is an observed versus predicted plot. The values of the observed age are plotted against the predicted values from the regression model. The plot shows that the values are equally distributed; hence, the regression model fits the trend of the data reasonably well. The residual plot (Fig. 3) shows the adjusted age or predicted values from the derived regression equation plotted against the residual that is, observed minus predicted age. The residual plot did not show any obvious pattern with only three possible outliers. Hence, both diagnostic plots support our chosen regression model to estimate age.

Table 2
Stepwise regression analysis.

Model	Value	Std. error	t	'p' Value	95.0% Confidence interval for B	
					Lower bound	Upper bound
Constant	16.025	0.043	373.602	<0.001	15.940	16.110
Second molar	−9.445	0.239	−39.462	<0.001	−9.920	−8.970
Canine	1.650	0.609	2.711	0.008	0.442	2.858

Table 3
Total variance of the regression model.

Model	R	R square	Std. error of the estimate	Change statistics				
				R square change	F change	df1	df2	Sig. F change
1	0.987[a]	0.973	0.21406	0.973	3632.458	1	99	0.000
2	0.988[b]	0.975	0.20751	0.002	7.349	1	98	0.008

[a] Reader 1.
[b] Reader 2.

5. Discussion

Age estimation is important from a forensic perspective and is especially useful in establishing the difference between the juvenile and the adult status of an individual in law cases, in illegal immigrations and in situations where the individuals do not have valid documentation of age. Chronologic age estimation by tooth development has been used since a long period.[17] The various methods of age estimation based on the teeth do not provide a common formula for the whole world. To ameliorate the accuracy of dental age estimation procedures, it is necessary to collect referral databases of panoramic radiographs of the same national and ethnic origin[18] and derive region-specific formulae for accurate age estimation.

In the present study, the European formula could not be applied to Indian samples as India has a population of mixed ethnicity and people belonging to various origins reside here. The study sample included individuals from Karnataka with at least the last two generations residing in Karnataka. This was done to ensure ethnic uniformity of the study sample, considering that the development of teeth varies among populations[19] and is genetically determined.[20]

In the present study estimation of chronological age was performed by measuring the open apices of the teeth excluding third molars of healthy children aged between 12 and 16 years. The maxillary teeth were not included as the apices of maxillary teeth are often obscured by superimposition from anatomical landmarks or errors from the radiographic procedures. This age group was selected as this age range forms a crucial factor to determine whether the child is a juvenile or an adult.

The panoramic radiograph is considered the best tool for age estimation in children because intraoral radiography is difficult to

Table 4
Median of the residuals.

	Mean	Median	Mode	SD	Min.	Max.	25 Q1	75 Q3
101	0.0000	−0.0348	−0.03	0.21116	−0.50	0.53	−0.1372	0.1148

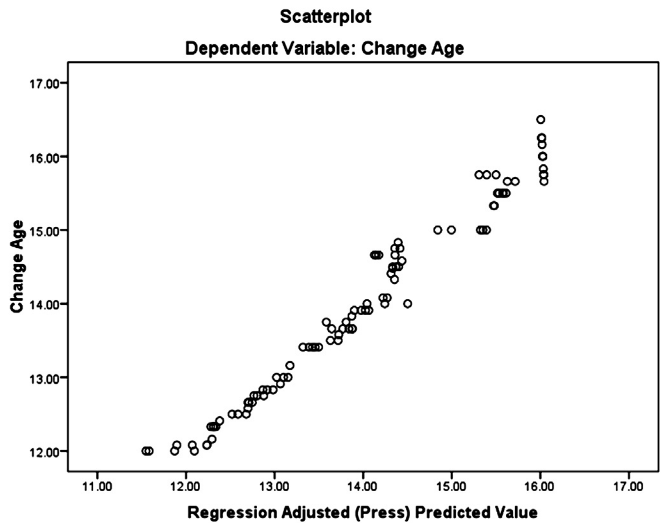

Fig. 2. Observed versus. predicted plot.

obtain in children without image distortion. Panoramic radiographs are ideal screening tools as they are inexpensive, readily available, provide an unobstructed view of the entire dental arch and have less radiation exposure. Wood[21] argued that the panoramic radiograph being a tomograph could result in teeth, especially those tilted in a buccolingual direction, falling out of the focal trough, resulting in misestimation of age. To overcome this disadvantage, all cases were screened for severe malocclusion and tilting of teeth.

When open apices were measured on digitised panoramic images (indirect digitisation) of mandibular teeth, it was shown that there were no significant intra- and interobserver differences. Based on this result, we concluded that this technique could produce reliable and reproducible intra- and interobserver measurements.

Our study showed no statistical differences in dental age estimation between male and female samples, which showed that gender did not show significant influence on age estimation and was therefore excluded as a factor in the model equations. It is possible that poor nutritional status, especially of girls, has

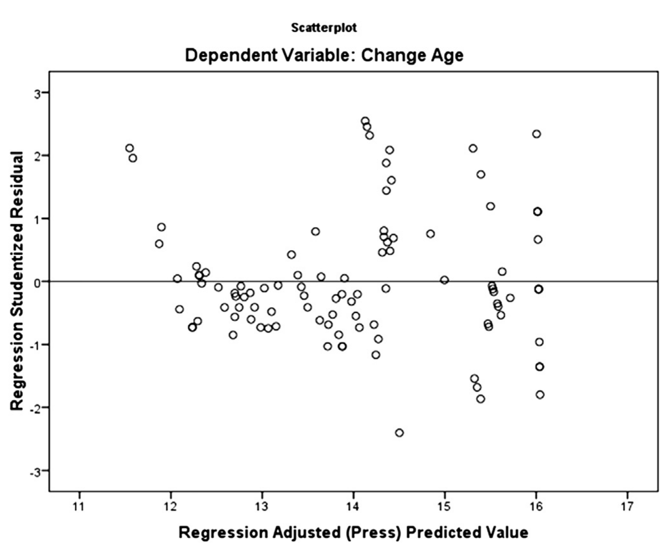

Fig. 3. Residual plot.

important implications in terms of their capacity for physical work and adverse reproductive outcomes, as was in fact observed in one study[14] but contrary to the results found in another.[22,23] Hence, the maturation of girls and boys in India may occur at about the same time because the early maturation of girls, when compared with boys, may be offset by malnutrition and the greater amount of physical work required of them. The results found in this work, like those of others,[24] indicate that more attention should be focussed on the possible differences between children of different origins.

In the present study only the variables 'canine' and 'second molar' contributed significantly to the fit and were therefore included in the regression equation. The canines and second molars are consistent teeth of the arch and can be reliable parameters for age estimation. Canines have been used in other age estimation methods such as Kvaal's method[25] and have proved to be reliable in the estimation of age. Moreover canines are single-rooted teeth and the measurement of open apices is easier. Our method, based on the normalised open apices of the seven left permanent mandibular teeth, employed a second-degree polynomial function (Eq. (1)). The morphological variables explain 97.6% variance ($R^2 = 0.976$), which showed a median of the absolute value of residual error of less than 0.04 years, median $= -0.0348$ years, IQR $= 0.252$ years and a standard of estimate of 0.214. The median, which shows the observed age minus the predicted age, is less than 0.04 years and shows the accuracy by which this equation will estimate age as close as possible to the chronological age. In forensic sciences it is important that we assess the age close to the actual age of the individual.

A similar study was performed in a sample of North Indian and South Indian (Kerala) children by Balwant Rai et al.[26] The results showed that the variables 'gender' and 'second premolar' contributed significantly to the fit in contrast to our study where 'canine' and 'second molar' contributed significantly to the fit. As India has a population of mixed ethnicity, different variables were significant in both the studies. Therefore it is imperative to derive region-specific formulae.

When the derived regression equation is applied to older children (15–16 years) with closed apices, the estimated chronological age will be same regardless of their age. This is consistent with Cameriere et al.,[5] who proposed that age in younger children could be more accurately predicted than in older children. The significant decrease in accuracy in the oldest age cohort may be attributed to the almost complete maturation of the teeth in this age cohort.

The limitations of the study are that the derived regression equations give the same values for children with closed apices of the permanent teeth regardless of their age especially in the age group of 15–16 years. The derived regression equation is same for both the male and female gender and does not differentiate between a fast- or slow-maturing child.

The present research has confirmed that there is significant correlation between age and measurement of open apices. This method can be used for assessing age in forensic as well as legal contexts and based on these variables chronological age can be determined in the South Indian population.

Ethical approval

Approval from the ethical committee of the institution was obtained regarding the study.

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None declared.

Conflict of interest

There is no conflict of interest regarding this article and it has not been submitted elsewhere.

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